PROJECT REPORT

Wind Resource Maps of Maryland

Prepared for

State of Maryland
Maryland Energy Administration
Contract #2001-32-B043J

and

US Department of Energy
Philadelphia Regional Office
Order #DE-AP43-01R3-25005-00

Prepared by

Michael Brower
TrueWind Solutions, LLC

November 4, 2002

Project Report

Wind Resource Maps of Maryland

SUMMARY

This report presents the results of a wind mapping project conducted by TrueWind Solutions, LLC, for the Maryland Energy Administration and the US Department of Energy. Using its MesoMap system, TrueWind has produced maps of mean wind speed at 30 m, 50 m, 70 m, and 100m height and of mean wind power at 50 m height, on a 200 m grid covering Maryland. In addition TrueWind has produced a CD-ROM containing GIS-compatible wind resource data and overlays and an interactive GIS viewer.

The maps indicate that the best wind resource areas are concentrated along ridges of western Maryland near Frederick and Cumberland and along the eastern shores of Chesapeake Bay and the Atlantic coast. The predicted wind speed and power along the western ridgetops would easily suffice to support large-scale wind energy projects of the sort being considered in similar locations in southern Pennsylvania. While the coastal resource is not as good, small wind turbines as well as large turbines adapted to low-speed regimes are a possibility.

The report also describes the validation of the maps carried out by TrueWind Solutions and the National Renewable Energy Laboratory (NREL). The validation has established that the maps are reasonably consistent with surface wind measurements at the 14 locations (including offshore) for which such data were available. The root-mean-square error in speed at 50 m, after accounting for uncertainty in the data, is about 0.3 m/s, or 5%.

The following sections present the maps and describe the validation process and results. For background information on the MesoMap system and mapping methodology, see Addendum 1. For guidelines on using the maps, see Addendum 2. For a description of the accompanying data CD and instructions for use, see Addendum 3.

WIND MAPS

Maps 1-4 show the predicted mean wind speed across Maryland at heights of 30 m, 50 m, 70 m, and 100 m, respectively, above the effective ground level.[1] Seventy meters is a typical tower height for the current generation of large wind turbines of 750 KW to 2 MW rated capacity; 30 m is a typical height for small turbines of up to 50 KW rated capacity. Map 5 shows the predicted mean wind power density at 50 m height in the

[1] In dense forest, the effective ground level is the canopy height, which is estimated to be 2/3 the height of the tree tops. Thus if the average tree height is 15 m (45 ft), the effective ground level is about 10 m (30 ft), and a map height of 65 m corresponds to a height of 75 m above ground.

NREL standard wind resource classes. This map is especially useful for comparing the new resource map with the previous map in the national wind atlas.[2]

The mean speed and power describe different aspects of the wind resource, and both can be useful in different ways. The mean speed is the easiest for most people to relate to and is consequently the most widely used. However, it does not directly measure the power-generation potential in the wind. The mean wind power, which depends on the air density and the cube of the wind speed, is regarded by some experts as a more accurate indicator of the wind resource when assessing wind project sites. Generally speaking, commercial wind power projects using large turbines require a mean speed of at least 7 m/s or mean power of at least 400 W/m^2 (NREL class 4). Small turbines are designed to operate at lower wind speeds, and may be useful at mean speeds (at 30 m height) as low as 5-6 m/s (NREL class 2 to 3).

The wind maps show that much of Maryland has a class 1-2 wind resource, with mean wind speeds at 70 m of 5.5-6.5 m/s. The reason for the moderate wind speeds overall, despite strong winds aloft much of the year, is the high surface roughness of the forested land. Trees create friction which reduces the near-surface wind speeds. Where hills and mountains protrude high enough above the landscape, however, the wind is accelerated, and the resource is predicted to reach class 4-6, or 7-8 m/s. The hills in western Maryland concentrate the wind resource exceptionally well because they are oriented perpendicular to the prevailing westerly and northwesterly winter winds. The threshold elevation at which the wind resource becomes attractive for large wind projects in western Maryland appears to be about 550-600 m.

The wind resource in central Maryland is moderate, but it improves near the coast because of the influence of the Atlantic Ocean and Chesapeake Bay. Offshore, especially on the Atlantic side, the wind resource is predicted to reach 7.5-8.5 m/s at 70 m, or NREL class 4-5.

It should be emphasized that the mean wind speed or power at a site may differ substantially from the predicted values where the elevation, exposure, or surface roughness differs from that assumed by the wind mapping system. The map estimates were developed using 1:250,000 scale topographical data and 1:100,000 scale land cover data from the US Geological Survey. The accuracy of these data should be verified in areas where wind projects are being considered. See Addendum 2 for guidelines on the use of the maps.

MAP VALIDATION AND ADJUSTMENTS

The wind maps were initially produced without reference to any surface wind data. To assess the maps' accuracy, we compared the 50 m map values with data provided by NREL for 14 locations throughout the state (including two in Virginia on the eastern shore). The data included eight airports, four Coast Guard stations, the Hills Point automated weather station operated by AWS Convergence Technologies, and a NASA station on Wallops Island, Virginia. The tower height at the AWS site was 40 m; most of

[2] *Wind Energy Resource Atlas of the United States* (Department of Energy, 1986).

the others were short towers of 4 to 12 m height, with the exception of a rooftop mast at 18.9 m at the Hagerstown Airport.

The validation was carried out in the following steps:

1. Station locations were verified and adjusted, if necessary, by comparing the quoted elevations and station descriptions against the elevation and land cover maps. Where there was an obvious error in position, the station was moved to the nearest point of correct elevation.
2. The observed mean speed and power were extrapolated to a common reference height of 50 m using the power law. The shear exponent was estimated from the available information about each site. The estimated values ranged from 0.13 at the coastal sites to 0.15-0.25 at the airports.
3. The error margin for each data point was then estimated as a function of two factors: the tower height and the number of years of measurement. The tower height enters the equation because of uncertainty in the wind shear. We assumed an uncertainty margin of 0.05 in the estimated wind shear exponent, except for the buoy, for which the margin was 0.03.

   Because of interannual variability, the mean speed measured over a limited period of time may differ from the true long-term mean. We assumed the the standard error after one year of measurement is 6%,[3] and that the error margin varies inversely with the square root of the number of years.

   The two uncertainties were then combined in a least-squares sum as follows:

   $$(1)\quad e = \sqrt{\left(\left(50/H\right)^{0.05} - 1\right)^2 + \left(\frac{0.06}{\sqrt{N}}\right)^2}$$

   where H is the height of the anemometer and N the number of years of measurement. For example, if the mean speed for a 10 m tower with a two-year record was 4.6 m/s, and the estimated shear was 0.18, then the estimated 50 m speed would be 6.1 m/s with a standard error of 9.4%, or 0.6 m/s.
4. Next, the predicted and measured/extrapolated speed and power were compared, and the map bias (map speed or power minus measured/extrapolated speed or power) was calculated for each point. The results were then displayed in a scatterplot and on a bias map. A scatterplot allows the quick identification of outlying points and reveals the overall quality of the match between prediction and measurement. A bias map, on the other hand, is useful for revealing spatially correlated error patterns. If a cluster of stations have similar errors in sign and magnitude, it is more likely to reflect a real problem in the map than if the errors appear randomly distributed.

Table 1 summarizes the results. The preliminary maps were on average higher than the measured and extrapolated speed and power by about 0.3 m/s and 28 W/m^2, respectively.

[3] This is equivalent to the rule of thumb that the mean speed after one year of measurement will be within 10% of the long-term mean with 90% confidence.

Table 1. Validation Summary

	Number of Stations	Mean Bias	Total RMS Discrepancy	Model-Only Error
Speed	14	0.3 m/s (4%)	0.5 (8.4%)	0.3 (4.6%)
Power	14	28 W/m^2 (13%)	60 (26.6%)	36 (16.3%)

The total root-mean-square (RMS) discrepancy in speed and power was 0.5 m/s and 60 W/m^2, respectively, the latter being about one-half a power class. (The wind power RMS discrepancy in percentage terms is larger than the wind speed discrepancy because the power varies as the cube of the speed.) However, the total discrepancy reflects possible errors both in the model and the data and thus probably overstates the error of the map alone. The model-only error, shown in the last column, is calculated by subtracting (in a least-squares sense) the standard error of the data from the total RMS discrepancy:

$$(2)\quad e_{MODEL} \approx \sqrt{e_{TOTAL}^2 - e_{DATA}^2}$$

This equation assumes that the errors in the model and data are random, normally distributed, and independent of one another. As Table 1 indicates, the model-only error in speed is about 0.3 m/s, or 4.6%.

The scatterplot in Figure 1 compares the predicted and measured-extrapolated mean wind speeds at 50 m height. The linear trend line, which is forced through the origin, shows that the map estimates are on average higher than the measured/extrapolated speeds (the slope of the line is less than one); the model nevertheless explains about 75% of the variance in the measured and extrapolated speeds.

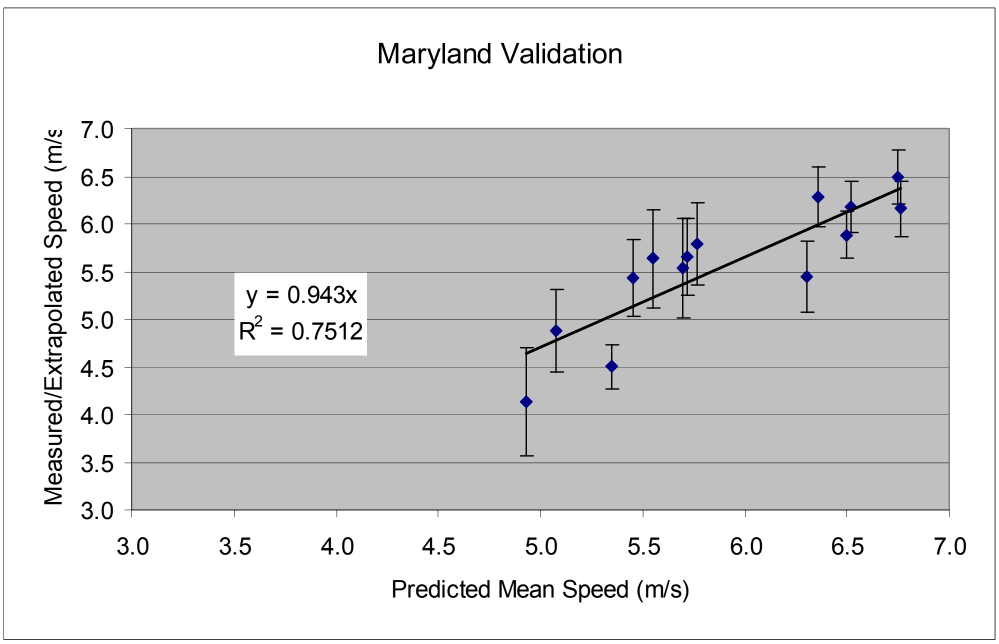


Figure 1. Scatterplot of predicted and measured/extrapolated wind speeds at 50 m height for 14 stations in Maryland. The error bars are calculated from the equation given in the text.

A key question is whether the apparent high bias of the map is ‘real’: does it indicate that the predicted speed is too high, or, on the contrary, does it reflect problems in the data? While a definitive answer is not possible with the data at hand, we suspect that the station data are at least partly at fault. Two examples illustrate the problem:

- The estimated mean speed at 50 m at Fort Meade was about 1.3 m/s below the estimated mean at Baltimore/Washington Airport, even though the two stations are only about 10 km (6 miles) apart. The map agrees well with the airport data, but is about 0.5 m/s higher than the Fort Meade data. It seems likely that the Fort Meade station is partially obstructed by trees or buildings; a higher wind shear should probably be assumed.
- The estimated 50 m mean speed at the NASA Wallops Island location is 0.4 m/s less than that of the Wallops Airport, even though Wallops Island is right at the coast whereas the airport is about 4 km (3 miles) inland. The map agrees with the data at the airport, but is about 0.9 m/s higher than the NASA data. It seems likely that trees or buildings around the NASA site may have obstructed the measurements.

Based on these considerations, both NREL and TrueWind concluded that the predicted wind speed and power were probably not too high in most areas. One exception may be valleys in western Maryland, where stability affects appear to reduce the wind speed at night to a larger degree than predicted by the model. In the absence of data to confirm this, however, the conclusion is tentative. Consequently, NREL and TrueWind agreed that no adjustments would be made to the maps.

CONCLUSIONS

The MesoMap system has been used to predict the wind energy resource in Maryland on a 200 m grid. Maps have been produced showing the predicted mean wind speed at 30, 50, 70, and 100 m height, and the mean wind power at 50 m height, above the effective ground level (forest canopy or ground). The maps indicate that the most favorable winds are found along the shore of the Maryland Bay and Atlantic Ocean, as well as offshore. The wind resource inland is modest.

The maps agree well with available wind data extrapolated to 50 m. Although the predicted speed was significantly higher than the measured at several locations, this was ascribed to obstructions or other problems with the data, which were taken in most cases at low tower heights. No adjustments were made to the maps.

Nevertheless, caution should be applied when using the maps, especially because local conditions such as elevation and surface roughness (land cover) may differ from that assumed by the model.

ADDENDUM 1: DESCRIPTION OF THE MESOMAP SYSTEM

The MesoMap system consists of three key components: models, databases, and computer and storage systems. These components are described below.

Models

At the core of the MesoMap system is MASS (Mesoscale Atmospheric Simulation System), a numerical weather model that has been developed over the past 20 years both as a research tool and to provide commercial weather forecasting services. MASS embodies the fundamental physics of the atmosphere including conservation of mass, momentum, and energy, as well as the moisture phases, and it contains a turbulent kinetic energy module that accounts for the effects of viscosity and thermal stability on wind shear. As a dynamical model, MASS simulates the evolution of atmospheric conditions in time steps as short as a few seconds. This creates great computational demands requiring the use of powerful workstations and multiple parallel processors. However, MASS can be coupled to a faster model, WindMap, a high-resolution mass-consistent wind flow model. Depending on the size and complexity of the region and requirements of the client, WindMap may be used to increase the spatial resolution of the MASS simulations.

Databases

The MASS model uses a variety of online, global, geophysical and meteorological databases. The main meteorological inputs are reanalysis data, rawinsonde data, and land surface measurements. The reanalysis database – the most important – is a gridded historical weather data set produced by the US National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR). The data provide a snapshot of atmospheric conditions around the word at all levels of the atmosphere in intervals of six hours. Along with the rawinsonde and surface data, the reanalysis data establish the initial conditions as well as updated lateral boundary conditions for the MesoMap simulations. However, the model itself determines the evolution of atmospheric conditions within the region based on the interactions among different elements in the atmosphere and between the atmosphere and the surface. Because the reanalysis data are on a relatively coarse, 200 km grid, the MesoMap system is run in several nested grids of successfully finer mesh size, each taking as input the output of the previous nest, until the desired grid scale is reached. The outermost grid typically extends several thousand kilometers.

The main geophysical inputs are elevation, land cover, vegetation greenness (normalized differential vegetation index, or NDVI), soil moisture, and sea-surface temperatures. The elevation data normally used by MesoMap were produced by the US Geological Survey in a gridded digital elevation model, or DEM, format from a variety of data sources.[4] The US Geological Survey, the University of Nebraska, and the European Commission's Joint Research Centre (JRC) produced the land cover data in a cooperative project. The land cover classifications are derived from the interpretation of Advanced Very High Resolution Radiometer (AVHRR) data – the same data used to calculate the NDVI. Both land cover and NDVI data are translated by the model into biophysical parameters such as surface roughness, albedo, emissivity, and others. The nominal spatial resolution of all of these data sets is 1 km. Thus, the standard output of the MesoMap system is a 1 km

[4] The US Defense Department's high-resolution Digital Terrain Elevation Data set is the principal source for the global 1 km elevation. Gaps in the DTED data set were filled mainly by an analysis of 1:1,000,000 scale elevation contours in the Digital Chart of the World (now called VMAP).

gridded wind map, although higher resolution maps can be produced if the necessary topographical and land cover data are available. In the United States, the final map resolution typically ranges from 100 m to 400 m.

Computer and Storage Systems

The MesoMap system requires a very powerful set of computers and storage systems to produce wind resource maps at a sufficiently high spatial resolution and with a fast turnaround time. To meet this need TrueWind Solutions has created a distributed processing network consisting of 54 individual Pentium II processors and 1.5 terabytes of hard disk storage. Since each processor simulates a sequence of days independently from the others, a project can be run on this system 50 times faster than would be possible with any single processor. To put it another way, a typical MesoMap project requiring 2 CPU-years of processing can be completed in just 2 weeks. The typical project also generates around 500 GB of data.

The Mapping Process

The MesoMap system creates a wind resource map by simulating weather conditions over 366 days selected from a 15-year period. The days are chosen through a stratified random sampling scheme so that each month and season is represented equally in the sample. Each simulation generates wind and other weather variables (including temperature, pressure, moisture, turbulent kinetic energy, and heat flux) throughout the model domain, and the information is stored at hourly intervals. When the runs are finished, the data files are compiled and summarized in a variety of formats, including most importantly color-coded maps of mean wind speed and power density at various heights above ground and databases containing wind frequency distribution parameters. The results are then compared with available land surface and ocean surface wind measurements, and if significant discrepancies are observed, adjustments may be made to the wind maps or the runs may be repeated with a different model configuration.

Accuracy of the Method

TrueWind has compared the MesoMap predictions with high-quality measurements from tall towers in several regions and climates.[5] These comparisons indicate that the standard error in mean wind speed is usually 7% or less once the uncertainty in the data are removed. The errors are usually driven by one or more of the following factors, which are listed in approximate order of decreasing importance:

- Variations in topography and land cover not resolved at the model grid scale
- Errors in the land cover data bases
- Finite sample size
- Errors in the meteorological data

---

[5] See Michael Brower, Bruce Bailey, and John Zack, “Micrositing with MesoMap,” Proceedings of Windpower 2002, American Wind Energy Association (2002).

The first is usually the most important. With a sufficiently high resolution at both the MASS and WindMap scales, we have found that the model-only standard error can usually be reduced to around 3-6%. What resolution is "sufficiently high" depends on several factors including the complexity of the terrain and whether there are any land-ocean boundaries within the domain being mapped. Even where a higher resolution is clearly desirable, however, budgetary and schedule considerations may limit our ability to reduce the grid spacing of the model runs.

Errors in the land cover data, and especially the translation to surface roughness, are perhaps the next most common problem. These errors can usually be reduced or eliminated by applying site-specific adjustments to the surface roughness based on field surveys and aerial photography. (The method is described in Addendum 2.)

The finite sample size (366 independent days) introduces an uncertainty margin of, typically, 3-4%. However the uncertainty can be larger where the wind speed frequency distribution is unusually broad – for example, if the wind resource varies greatly by season.

Errors in the meteorological data are probably of little concern in the United States and other developed, but may be significant in developing countries where data collection is relatively sparse.

ADDENDUM 2: GUIDELINES FOR USE OF THE MAPS

The following may be useful guidelines for interpreting and adjusting the wind speed estimates in the maps, especially in conjunction with the accompanying CD-ROM. The CD-ROM allows users to obtain the "exact" wind speed value at any point on the map, and it also provides the elevation and surface roughness assumed by the model, which are needed to apply the adjustment formulas given below.

1. The maps assume that all locations are free of obstacles that could disrupt or impede the wind flow. "Obstacle" does not apply to trees if they are common to the landscape, since their effects are already accounted for in the predicted speed. However, a large outcropping of rock or a house would pose an obstacle, as would a nearby shelter belt of trees or a building in an otherwise open landscape. As a rule of thumb, the effect of such obstacles extends to a height of about twice the obstacle height and to a distance downwind of 10-20 times the obstacle height.
2. Generally speaking, points that lie above the average elevation within a 200×200 m grid cell will be somewhat windier than points that lie below it. A rule of thumb is that every 100 m increase in elevation will raise the mean speed by about 1 m/s. This formula is most applicable to small, isolated hills or ridges in otherwise flat terrain.
3. The roughness of the land surface – determined mainly by vegetation cover and buildings – up to 1-2 kilometers away can have an important impact on the mean wind resource at a particular location. If the roughness is much lower than that assumed by the mapping system, the mean wind speed will probably be higher. Typical values of roughness range from 0.01 m in open, flat ground without significant trees or shrubs, to 0.1 m in land with few trees but some smaller shrubs, to 1 m or more for areas with many trees. These values are only indirectly related to the

size of the vegetation; they are actually scale lengths used in meteorological equations governing the structure of the boundary layer.

An approximate speed adjustment *in the direction of the roughness difference* can be calculated using the following equation:

$$\frac{v_2}{v_1} \approx \frac{\log\left(500/z_{01}\right)}{\log\left(h/z_{01}\right)} \times \frac{\log\left(h/z_{02}\right)}{\log\left(500/z_{02}\right)}$$

v_1 and v_2 are the original and adjusted wind speeds at height h (in meters above the effective ground level), whereas z_{01} and z_{02} are the model and actual surface roughness values (in meters). As an example, suppose the land cover data used by the model showed an area to be forested in all directions with an estimated roughness value of 1 m, whereas in fact the land was fairly open in all directions with an estimated roughness value of 0.1 m. For h = 65 m, the above formula gives

$$\frac{v_2}{v_1} \approx \frac{\log\left(500/1\right)}{\log\left(65/1\right)} \times \frac{\log\left(65/0.1\right)}{\log\left(500/0.1\right)} = 1.13$$

implying the model wind speed should be increased by about 13%.

This formula assumes that the wind is in equilibrium with the new surface roughness above the height of interest (in this case 65 m). When going from high roughness to low roughness (such as from forested to open land), the clearing should be at least 1 km wide for the benefit of the lower roughness to be fully realized. However, when going from low to high roughness, the reduction in wind speed may be felt over a much shorter distance. For this and other reasons, the formula should be applied with caution. Where doubts arise, users are urged to obtain the advice of a qualified consulting meteorologist.

ADDENDUM 3: THE DATA CD-ROM

The CD-ROM accompanying this report contains a free program called ArcExplorer 2, produced by ESRI, which allows users to view, query, copy, and print maps in an interactive environment. This addendum contains basic instructions for using the ArcExplorer program and associated maps and data bases. For detailed instructions, see the ArcExplorer on-line help file or visit www.esri.com/software/arcexplorer/index.html. The CD-ROM contains additional data files not used by ArcExplorer which may be imported into ArcInfo, ArcView, or other GIS programs. These files are described at the end of this addendum.

All coordinates in the data files are in meters referenced to the Universal Transverse Mercator coordinate system, zone 18, WGS84 datum.

Using Arcexplorer

STEP 1. SYSTEM REQUIREMENTS AND INSTALLATION

The first step is to install the ArcExplorer program on your system. According to ESRI, the maker of ArcExplorer, ArcExplorer 2 works on Windows 98/2000/NT operating systems. However, users report that it also works on Windows 95 and Windows Me operating systems. Because of the large data files, it is recommended that you have at least 128 MB of RAM.

Execute the program called ae2setup.exe found on the CD-ROM root directory. The setup program will guide you through the rest of the process. The data files can be left on the CD-ROM, but if you have room, you should copy the data directories to your hard disk. That will give you much faster performance.

STEP 2. OPENING THE PROJECT

Start ArcExplorer either by clicking on the icon that was placed on your Desktop (if you chose that option during installation) or by choosing Start - Programs - ESRI - ArcExplorer.

Choose File - Open and navigate to the CD-ROM or to the directory where you placed the files. Open the project file (extension: AEP).

NOTE: The file may take several minutes to load, especially from CD.

STEP3. FINDING YOUR WAY AROUND THE MAIN SCREEN

After ArcExplorer finishes loading the project, you should see the main window with a color wind map resembling the maps presented in this report. You may adjust the shape of the window to fit the map by dragging on its corners or sides. Notice that below the main map the X and Y position of the mouse pointer (in meters in UTM or state plane coordinates) is shown, along with the scale of the map and a scale bar.

A small Overview Map may be visible in the lower left corner of the main window. As you zoom in on an area in the main map, you will see a red rectangle on the Overview which shows where you are.

MAP LAYERS

Look to the left of the map window. Here you see a legend with the names of each of the map layers (also called themes). Not all of the layers are visible on the map when you first open the project. Some will appear only when you zoom sufficiently far into the map. Typically the first two layers have _ROSE and _MAIN in their names. They are described below:

<u>XX_ROSE</u>. This layer contains wind rose data including the frequency, mean speed, and percent of total wind energy from each of 16 directions (starting due north clockwise around the compass). The points are displayed only at high magnification (see below for instructions on changing the magnification).

XX_MAIN. This layer is the main wind resource database. It contains the mean annual speed, wind power, and Weibull frequency distribution parameters. The points are displayed only at a high magnification.

Most of the other layers contain overlays such as rivers, roads, and county or state boundaries. The last few layers are bitmap images (called something like SPD50.BMP) which is used as a color backdrop for the other layers. The color bands are defined in 0.5 m/s increments; for a legend, see the maps provided at the end of this report.

Now look along the top of the main window where a number of icons are visible. Aside from Open, Close, Save, and other standard functions, several useful tools are found here. To find out what each one does, hold the mouse pointer over the icon for a couple of seconds and a description will appear.

Starting from the left on the second row of icons, verify the locations of the following tools: Zoom to Active Theme, Zoom In, Zoom Out, Identify, and Measure. Following is a brief description of each:

Zoom to Active Theme. This tool is very useful for restoring the map to its full (initial) size after zooming. A theme (map layer) is activated by clicking on its name in the legend on the left.

Zoom In and Zoom Out. These tools function just like they do in many other programs. After selecting the tool, the mouse looks like a magnifying glass. Each click of the magnifying glass within the main map increases or decreases the scale by a factor of two. If you click and drag the magnifying glass over an area, you will zoom directly to that area.

Pan (hand tool). This tool allows you to move the map around by clicking on it and dragging in any direction. You can also navigate by clicking on the red rectangle in the overview map and dragging it where you want to go. This can be especially useful when you are at high magnification.

Identify. This tool is used to get more information about features you select on the map. You will find it most useful for querying the wind speeds and other data in the MAIN and ROSE layers. To use the tool, first select a map layer by clicking on the name in the legend on the left. Then click on the icon and the mouse pointer will change to an "i" with a circle around it. Click on a feature in the selected map layer and a data table will appear. If features are close together, the data table may contain entries for several of them.

Measure. This tool is used to measure distances on the map. To use it you will first have to select a measurement unit (kilometers, meters, miles, or feet) by clicking on the small arrow to the right of the icon. After selecting the tool, click on the map at one point and drag to another and the distance "as the crow flies" will be displayed.

STEP 4. ZOOM AND DATA TABLES

Select the Zoom In tool and click several times anywhere on the map. Or you may find it easier and quicker to select a zoom area by clicking and dragging the pointer to form a rectangle. In any case, once the scale becomes small enough, a number of blue points and red circles should appear. Each point represents one data point in the MAIN layer. The circles represent points in the ROSE layers.

First select the MAIN theme by clicking on its name in the legend to the left of the map. You will notice that as you pass the mouse over the points in the map, a number will appear next to the mouse pointer. This is the mean speed (in m/s) at each point.

Now select the Identify tool and click on one of the points. A data table will appear showing the exact X and Y coordinates (in meters UTM), the latitude and longitude in decimal degrees, the elevation and roughness assumed by the model (both in meters), the mean speed, power, and the Weibull C and k factors. At first the field names will be listed in a mixed-up order. Click on the word Field at the top of the list and the field names will be alphabetized.

Close the data table and select the ROSE layer. Click on a circle and alphabetize the data table. The fields labeled FREQ 1...FREQ16 correspond to the frequency (in percent) from each direction of the compass. The fields SPEED 1...SPEED16 are the mean speeds for each direction (normalized to the average), and the POWER 1...POWER16 fields are the percent of total energy for each direction.

Note that in a 16-sector wind rose, each sector corresponds to the following direction ranges (in degrees from north):

Sector	*Degree Range*
1	348.75 - 11.25
2	11.25 - 33.75
3	33.75 - 56.25
4	56.25 - 78.75
5	78.75 - 101.25
6	101.25 - 123.75
7	123.75 - 146.25
8	146.25 - 168.75
9	168.75 - 191.25
10	191.25 - 213.75
11	213.75 - 236.25
12	236.25 - 258.75
13	258.75 - 281.25
14	281.25 - 303.75
15	303.75 - 326.25
16	326.25 - 348.75

If you want the data points and circles (or any of the other features) to appear at a different magnification, then go to the magnification level you want using the zoom in and out tools. Right click on the name of the layer and select Set Maximum Scale. If you zoom out from that scale, the layer will disappear. If you prefer to set the display manually each time, then select Remove Scale Factors. Then, to prevent the map layer from displaying at any scale, simply uncheck the box next to the theme name.

The symbols used in the map overlays can be changed by going to Theme Properties. Select a map layer, then choose Tools - Theme Properties from the menu.

STEP 5. SAVING, COPYING AND PRINTING MAPS

Once you have selected an area of interest, you can copy the map to the Windows clipboard or save it as a picture file (bmp or emf format) by selecting commands under the Edit menu. Or you can print it by selecting Print under the File menu.

Be warned that the maps produced directly from ArcExplorer are not of very high quality. To produce a better map, consider saving the wind map as a bmp or emf file and importing it into a graphics program, or using the bitmap images as backdrops in a GIS program such as ArcView, ArcInfo, or Idrisi.

STEP 6. FOR MORE INFORMATION

If you have questions about the ArcExplorer program, please see the on-line documentation under the Help menu, view the ArcExplorer manual in PDF format on the CD-ROM, or visit http://www.esri.com/software/arcexplorer/index.html. For help with or information about the data base or any other aspect of the wind maps, send an e-mail to mbrower@truewind.com.

Other Data Files on the CD-ROM

The other data files on the CD-ROM contain additional information or are in different formats for different applications. The directories are as follows:

BMP. This directory contains the bitmap images used as a backdrop in ArcExplorer. The BMP files are accompanied by ESRI "world files" which provide geographic referencing when used in a compatible program such as ArcView.

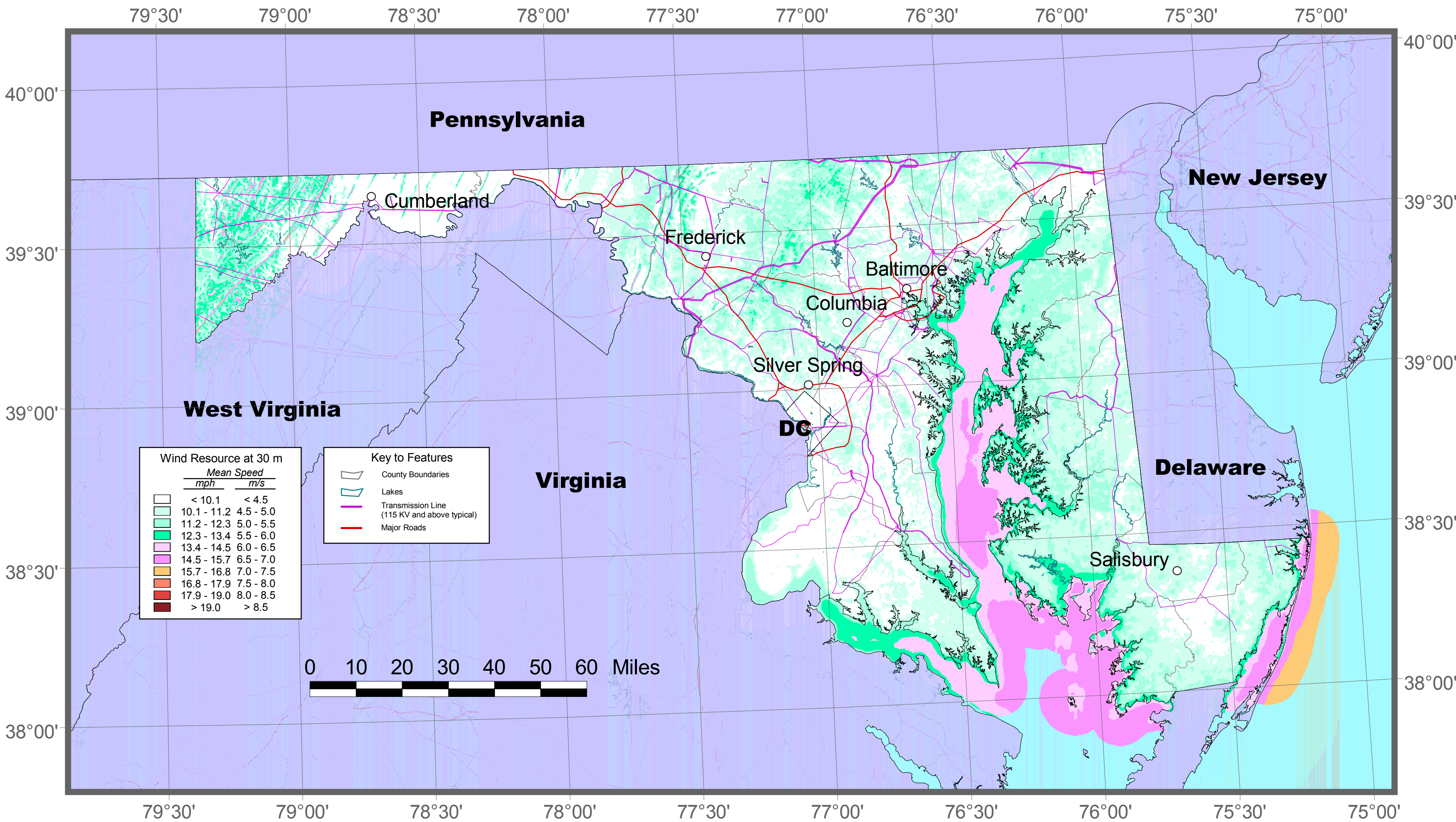
CSV. The files named XX_MAIN.CSV are comma-delimited databases containing, for each grid point, the X and Y coordinates, latitude and longitude, the assumed (model) elevation and roughness, the predicted wind speed and wind power data at each height, and Weibull distribution parameters C and k at 50 m. The files named XX_ROSE.CSV contain the wind rose frequencies, mean speeds, and percent of energy. There is one file of each type for the annual data and one file of each type for the seasonal data. The XX_MAIN data are on a 200 m grid, the XX_ROSE data are on a 2 km grid. The files can be easily imported into a database program such as Microsoft Access, or they can be used to create Shape files or other GIS overlay files in ArcView or ArcInfo.

FloatingPoint. The files in this program are ArcInfo-type floating point grid files containing the mean wind speed and power at each height. They can be imported into ArcView or ArcInfo and may be more convenient than using the CSV files. However only annual data are provided in this format.

Raster. These files provide an alternative bitmap-type format for use in compatible GIS programs. The format is recognized by ArcView and ArcInfo. However no wind speed or power data can be read directly from them – they indicate only the wind speed or power class, as shown in the wind maps.

Shape Files. These are the vector overlays used in ArcExplorer. They can be also be used in ArcView and ArcInfo, and they can be imported into many other GIS programs. Included among them are the annual XX_MAIN and XX_ROSE shape files used in the ArcExplorer project included on the CD-ROM.

Map 1. Wind Speed at 30 m

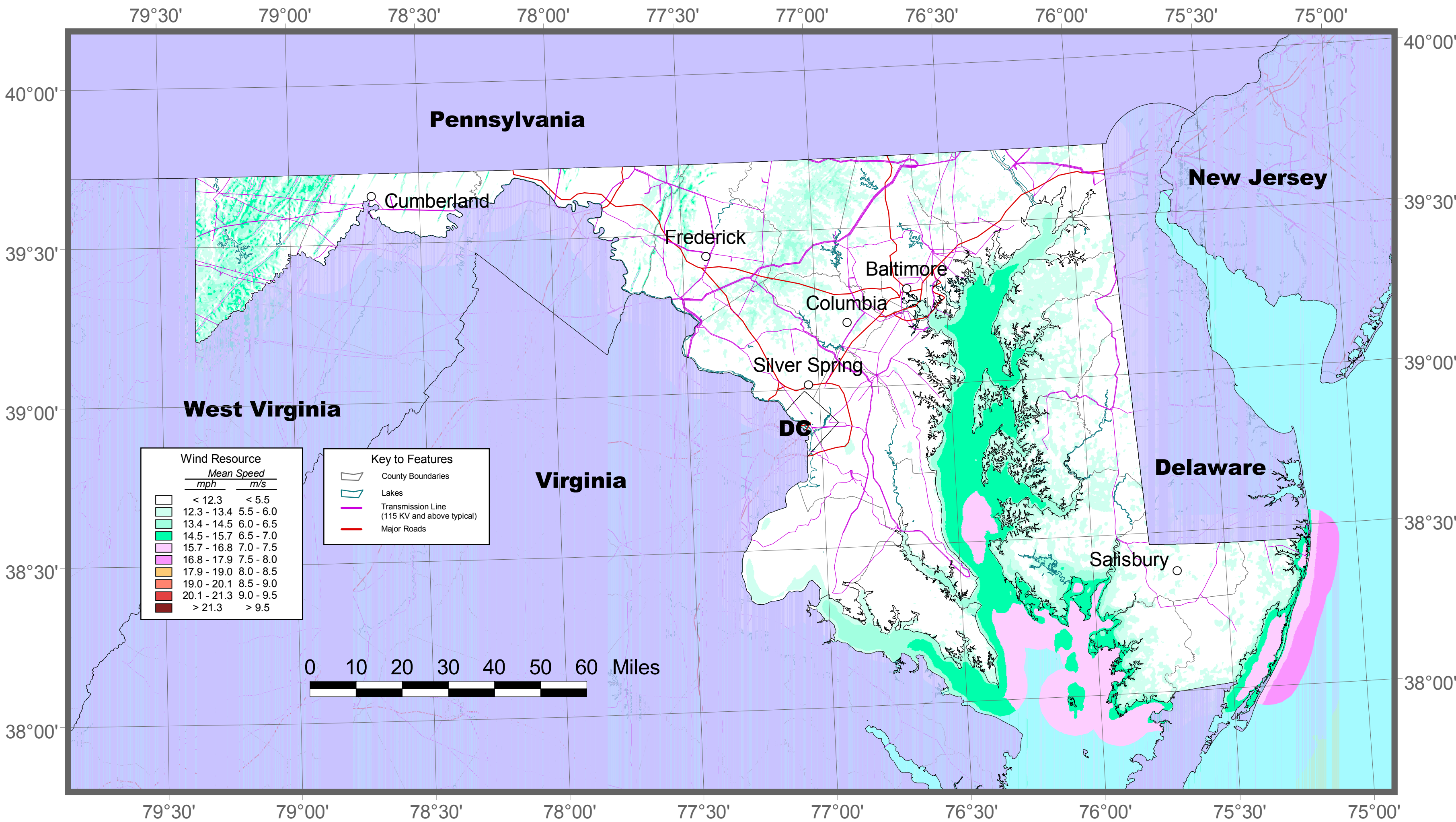


TrueWind Solutions

Projection: Universal Transverse Mercator (Zone 17)
Spatial Resolution of Wind Resource Data: 200 m

This map was created by TrueWind Solutions using the Mesomap system and historical weather data. It has been validated using available surface wind data by the National Renewable Energy Laboratory. Although it is believed to represent an accurate overall picture of the wind energy resource, estimates at any location should be confirmed by measurement.

Map 2. Wind Speed at 50 m

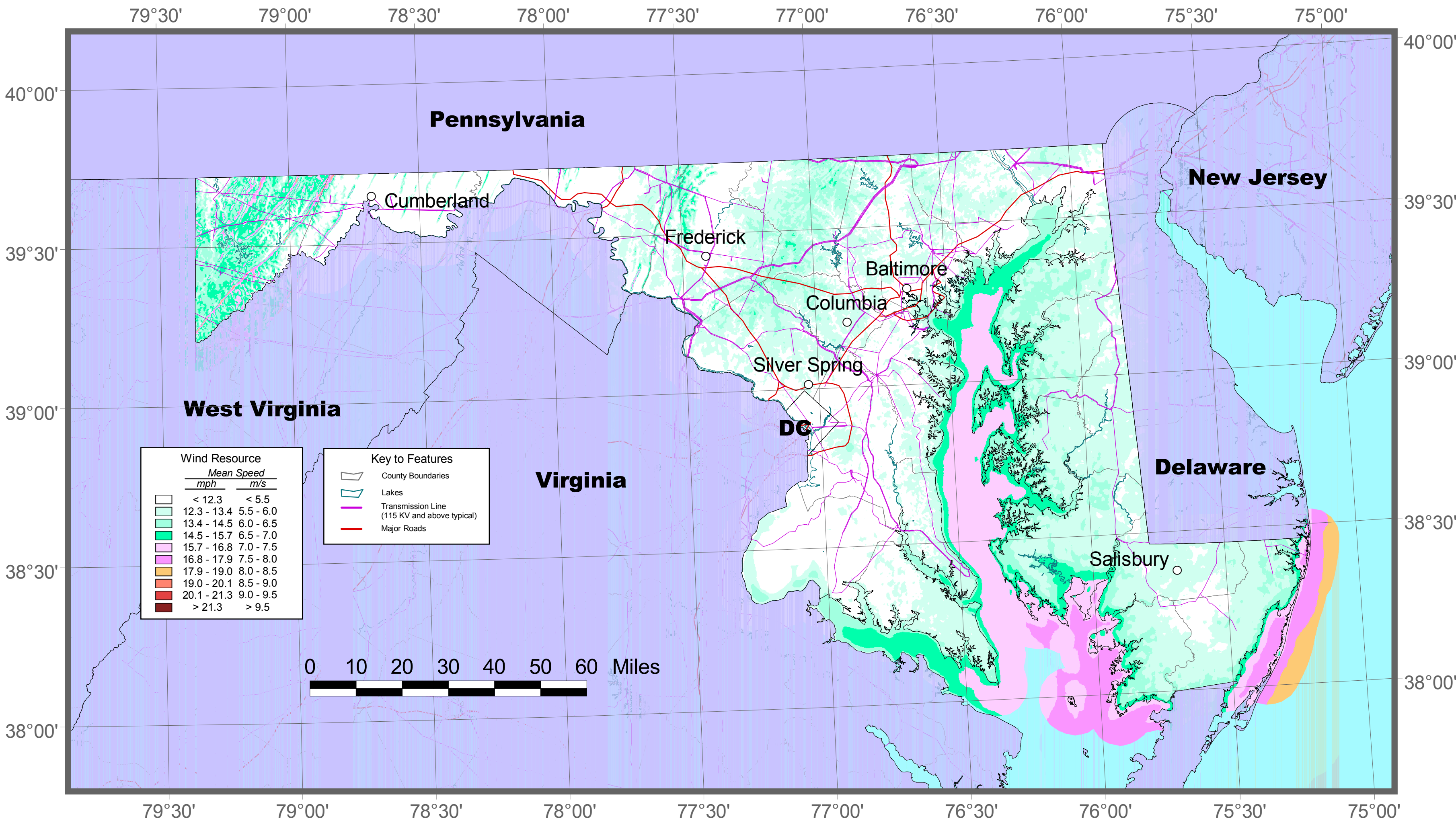


TrueWind Solutions

Projection: Universal Transverse Mercator (Zone 17)
Spatial Resolution of Wind Resource Data: 200 m

This map was created by TrueWind Solutions using the Mesomap system and historical weather data. It has been validated using available surface wind data by the National Renewable Energy Laboratory. Although it is believed to represent an accurate overall picture of the wind energy resource, estimates at any location should be confirmed by measurement.

Map 3. Wind Speed at 70 m

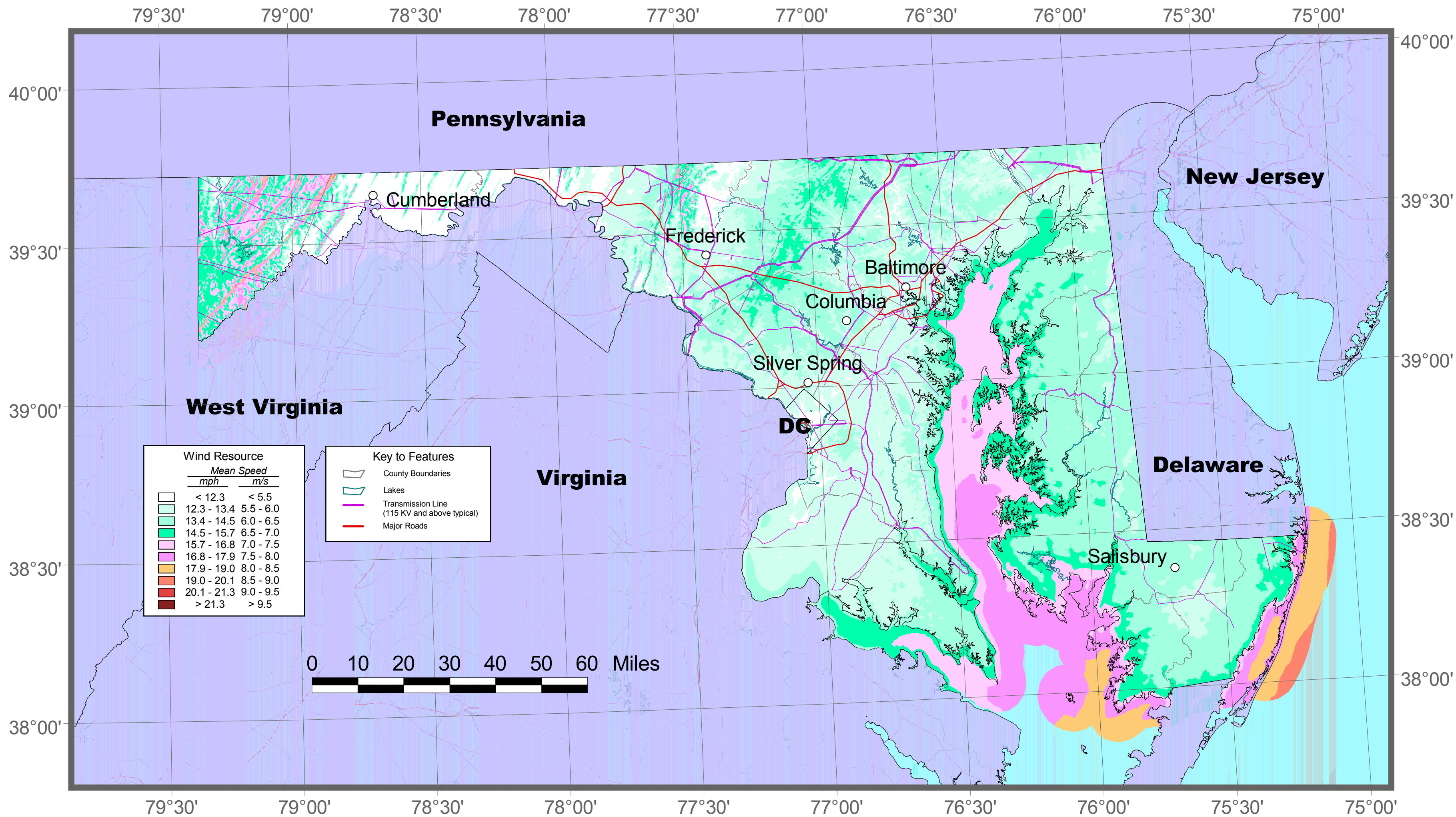


TrueWind Solutions

Projection: Universal Transverse Mercator (Zone 17)
Spatial Resolution of Wind Resource Data: 200 m

This map was created by TrueWind Solutions using the Mesomap system and historical weather data. It has been validated using available surface wind data by the National Renewable Energy Laboratory. Although it is believed to represent an accurate overall picture of the wind energy resource, estimates at any location should be confirmed by measurement.

Map 4. Wind Speed at 100 m

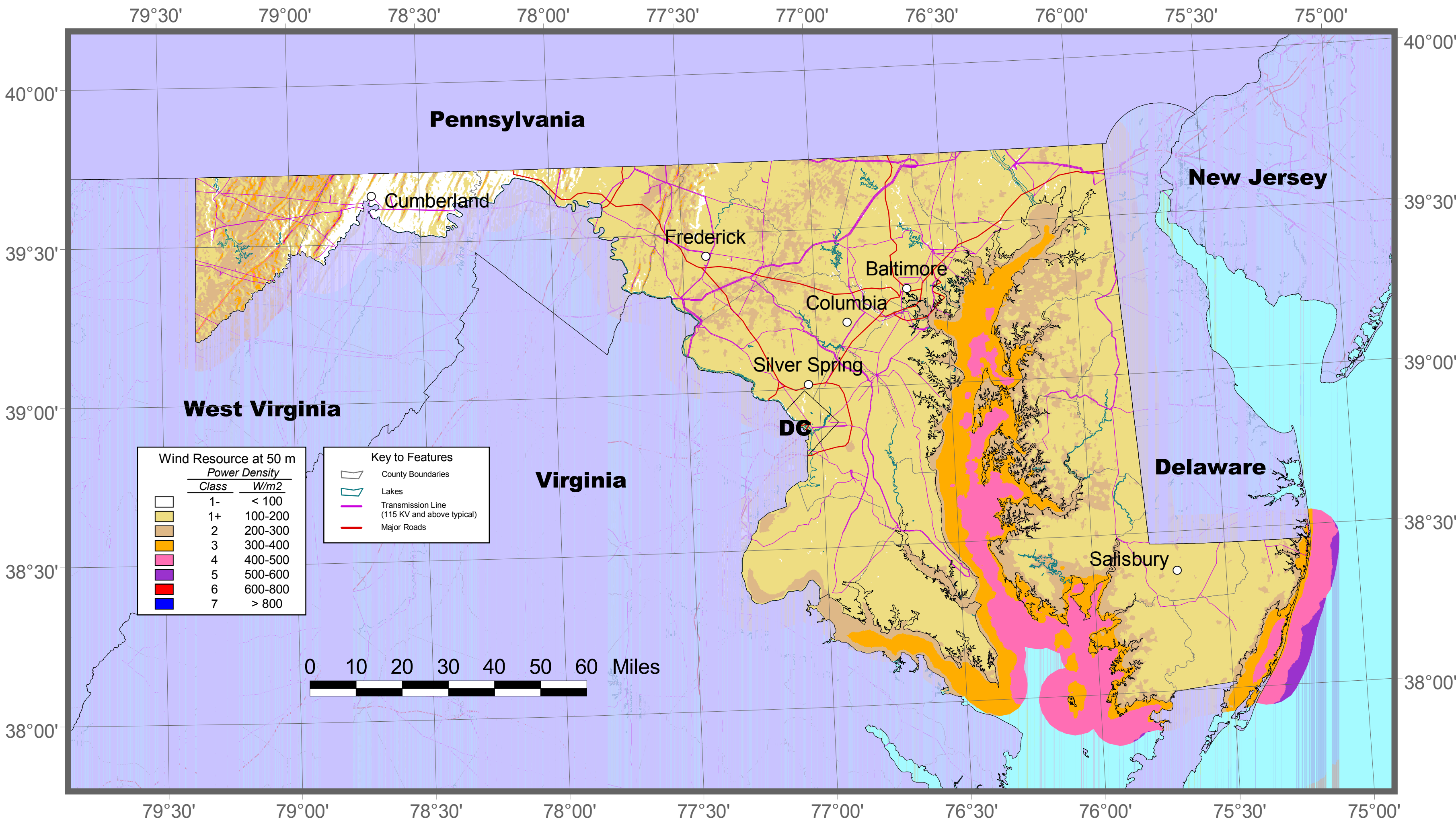


TrueWind Solutions

Projection: Universal Transverse Mercator (Zone 17)
Spatial Resolution of Wind Resource Data: 200 m

This map was created by TrueWind Solutions using the Mesomap system and historical weather data. It has been validated using available surface wind data by the National Renewable Energy Laboratory. Although it is believed to represent an accurate overall picture of the wind energy resource, estimates at any location should be confirmed by measurement.

Map 5. Wind Power at 50 m



TrueWind Solutions

Projection: Universal Transverse Mercator (Zone 17)
Spatial Resolution of Wind Resource Data: 200 m

This map was created by TrueWind Solutions using the Mesomap system and historical weather data. It has been validated using available surface wind data by the National Renewable Energy Laboratory. Although it is believed to represent an accurate overall picture of the wind energy resource, estimates at any location should be confirmed by measurement.